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AEROSPACE REPORT NO.  
ATR-79(7642)-3

Final Report  
Reduction and Analysis of ATS-6 Data  
(1 November 1978 - 30 June 1979)

Prepared by

G. A. PAULIKAS AND J. B. BLAKE  
Space Sciences Laboratory

1 June 1979

Prepared for

**NASA GODDARD SPACE FLIGHT CENTER**  
Greenbelt, Maryland 20771

Contract No. NAS5-23788



# Laboratory Operations THE AEROSPACE CORPORATION

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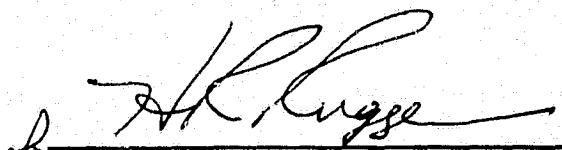
  
J. A. Paulikas, Director

Space Sciences Laboratory

  
J. B. Blake, Head

Space Particles and Fields Department

**Approved**

  
M. T. Weiss,

Vice President and General Manager  
Laboratory Operations

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## ABSTRACT

The scientific and technological results obtained by The Aerospace Corporation energetic particle spectrometer flown on ATS-6 are summarized. This experiment operated in the 1974-1979 time period, and returned data on energetic electrons trapped in the earth's radiation belt near synchronous altitude and on solar particles penetrating to this altitude.

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## ACKNOWLEDGMENTS

The operation of an experiment in space for more than half a decade reflects credit on the designers of the spacecraft and the experiment.

The success of experiment which yielded the results described in this report is attributable primarily to the careful electronics design done by Sam Imamoto. Henry Hilton was in charge of developing and maintaining the software used for data reduction and analysis.

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## I. INTRODUCTION

This report contains a summary of the progress in reducing and analyzing ATS-6 data during the period from 1 November 1978 to 30 June 1979. Because this report also marks the conclusion of the ATS-6 program, we also present here a compilation of all of the results obtained to date by The Aerospace Corporation energetic particle spectrometer on ATS-6. The results are presented in abstract format and referenced to publications, technical reports or technical memoranda listed in the bibliography. The report thus covers the operational history of the experiment since initial turn-on on Day 165, 1974. The information contained in the data base obtained by our experiment (now covering more than five years) has by no means been totally extracted. Indeed, the ATS-6 data set, when combined with similar data available from experiments flown on ATS-5 and ATS-1 provide us with a unique long-term overview of outer-zone magnetospheric dynamics. Analyses of these data will continue at a low level and can be expected to continue to yield important results.

## II. RESULTS

### A. Recent Progress (1 Nov. 1978 - 30 June 1979)

We have completed virtually all reduction of all ATS-6 data available to us since experiment turn-on (Day 165, 1974) (Table I). This includes the data obtained in 1978 after the termination of continuous data acquisition (Day 90, 1978). We are awaiting data covering the period during January-February of 1979 where ATS-6 experiments were operated in conjunction with the launch of the USAF Space Test Program Satellite P78-2 and expect to reduce these data as soon as they become available.

Research into the effects of the conditions in the interplanetary medium on energetic electrons trapped in the vicinity of ATS-6 has continued. Our results that the solar wind velocity is the single most important indicator of the intensity of trapped energetic electrons in the outer magnetosphere has been re-confirmed by examining the quality of this correlation at shorter time scales than the 1-day averages of the various parameters used in the original study. We have studied the correlation of energetic electron increases using one hour averages of the solar wind velocity and interplanetary magnetic field. We find that our results as reported in Reference A-6 still hold, i.e., the solar wind velocity very strongly (exponentially) governs the flux level, while the direction of the interplanetary magnetic field exerts a modest modulating influence on the flux of energetic electrons in the outer magnetosphere. We have also obtained 15-second time resolution data on the interplanetary magnetic field from NSSDC and are now in the process of examining the quality of the correlation by forming the appropriate averages of the interplanetary field  $B_Z$  (north) and  $B_Z$  (south) and products of these averages with appropriate powers of the solar wind velocity.

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Table I  
Summary of ATS-6 Data Reduction Status

Year	Days Experiment Operated	Days of Data Reduced	Percent
1974	200	190	95
1975	365	355	97
1976	366	340	93
1977	365	342	94
1978	102	94	92
1979	*		

\* Some data still expected.

## B. Summary of the Scientific Results Obtained 1974-1979

1. Data on the energetic electron fluxes at the synchronous orbit covering the 1967-1978 time interval, obtained by experiments flown on the ATS-1, ATS-5 and ATS-6 spacecraft have been combined and analyzed (Fig. 1). Long term (years) and short term (days) electron flux averages were found to correlate positively with corresponding averages of the solar wind velocity (Figs. 2, 3, 4, 5, 6, and 7). The direction of the interplanetary magnetic field also exerts a noticeable, although secondary influence (Fig. 8). Work is continuing to examine the correlation of the dynamics of the energetic electron population using highly time-resolved data on the parameters of the interplanetary medium. (Ref. A-2, A-6, B-3.)

2. A statistical compilation of the ATS-6 data have been prepared and the probabilities  $P(F > F_x)$  of observing a flux  $F$  greater than  $F_x$  have been computed for the various energy channels of the experiment and the several longitudes (corresponding to different magnetic latitudes) at which ATS-6 was stationed (Figs. 9, 10). It is found that the flux variability induced by changes in the properties of the interplanetary medium is far in excess of the variation due to changing the longitude of the observations. There are some indications, however, that the fluxes of energetic particles fall off somewhat more rapidly with increasing magnetic latitude than predicted by standard models.

These compilations have been used by NSSDC to develop the new AEI-7 model of energetic electrons in the magnetosphere. (Ref. A-3, A-5, B-7.)

3. The statistical compilation of ATS-6 data on energetic electrons has been analyzed to determine if a simple analytical relationship exists which can predict the maximum flux levels which electrons of various energies can reach. We find that the expression  $\log_{10} I^* (\text{cm}^{-2} \text{ sec}^{-1}) = - 2.53 \sqrt{E} (\text{Mev}) + 8.5$  describes the upper flux limit reached by energetic electrons at the synchronous altitude (Fig. 11). This expression,

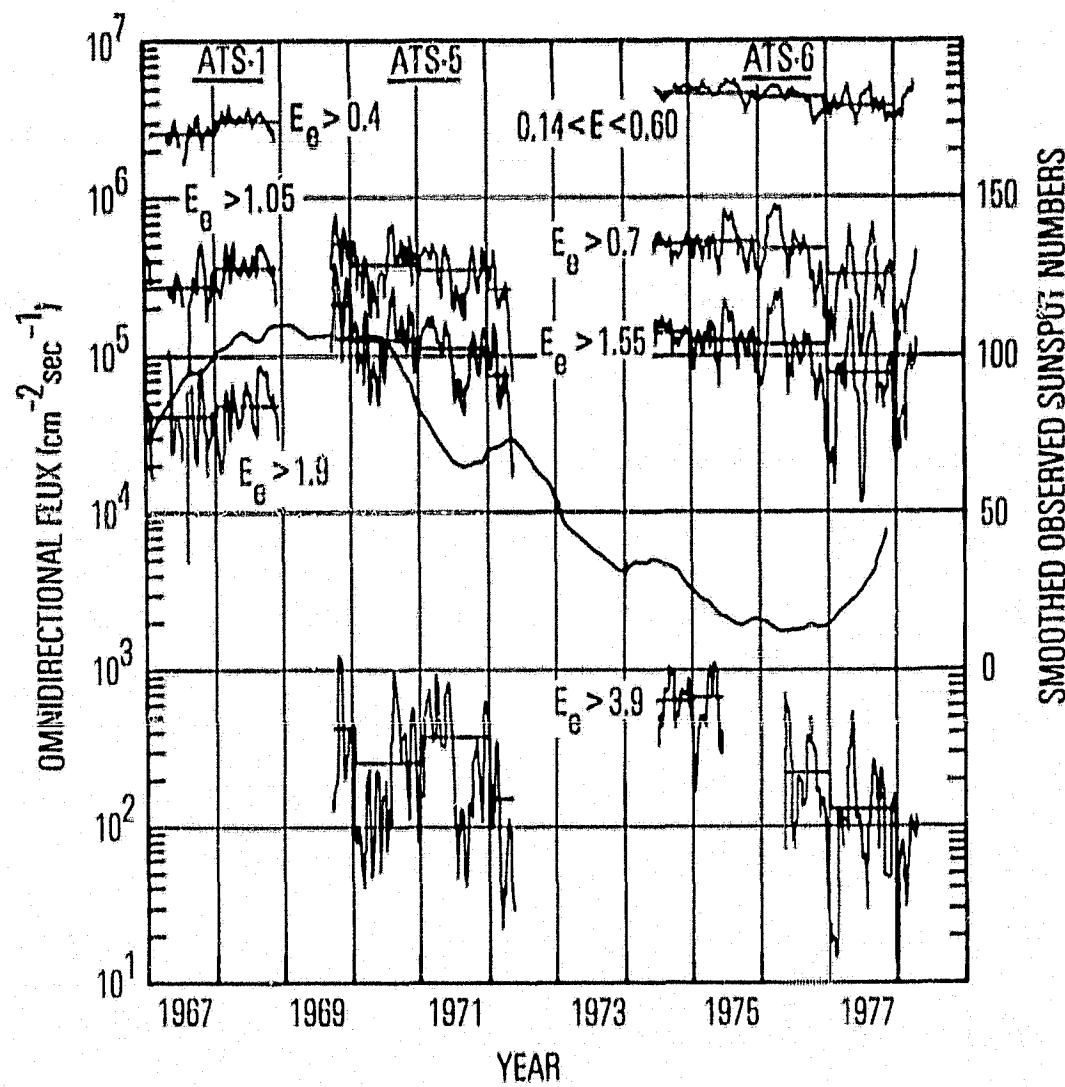


Figure 1. ATS-1, and ATS-5, ATS-6 energetic electron fluxes (running 27 day averages) as a function of time. ATS-5 data was normalized to ATS-6 data in mid 1974. The energy thresholds for the ATS-1, ATS-5 and ATS-6 channels are shown on the figure. The flux averages for each year are also indicated (solid horizontal lines). Superimposed on this graph is the Zurich monthly sunspot number, referred to the linear scale on the right. Gap in the ATS-6  $E_e > 3.9$  MeV data in 1975 and 1976 is caused by our rejection of suspect data.

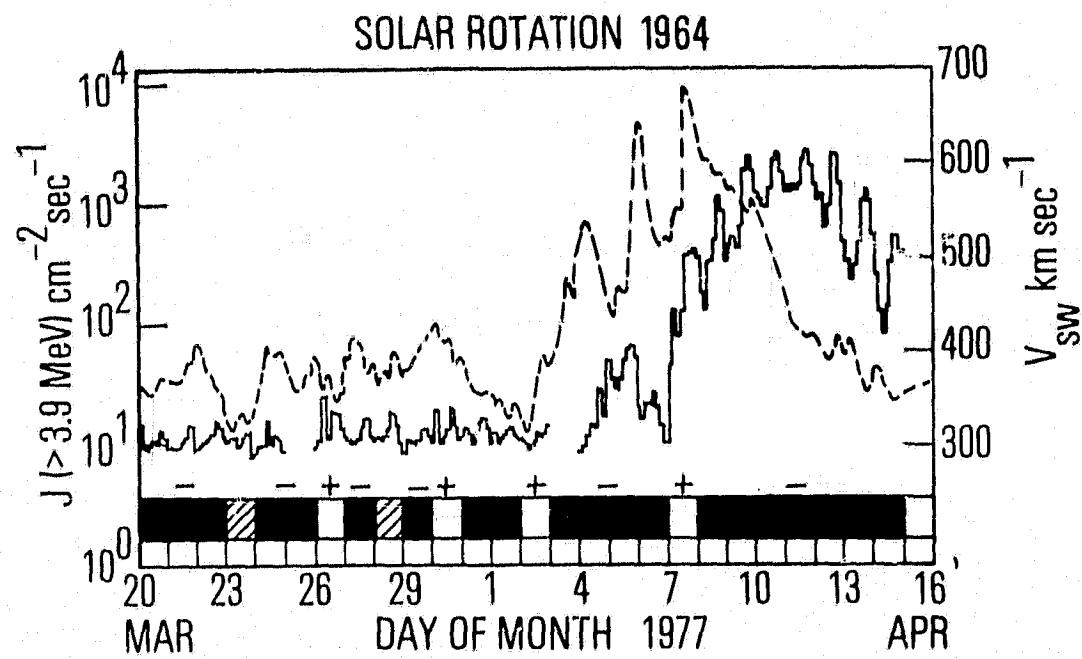


Figure 2. Flux of energetic electrons (solid curve with logarithmic scale at left) as a function of time for solar rotation 1964. Three-hour averages of electron flux are plotted. Solar wind velocity (dashed curve with linear scale at right) is superimposed on these data. The pattern at the bottom of the figure represents the IMF sector structure. This figure illustrates the close tracking, of the electron flux (after a delay of 2 days) and the velocity of the solar wind.

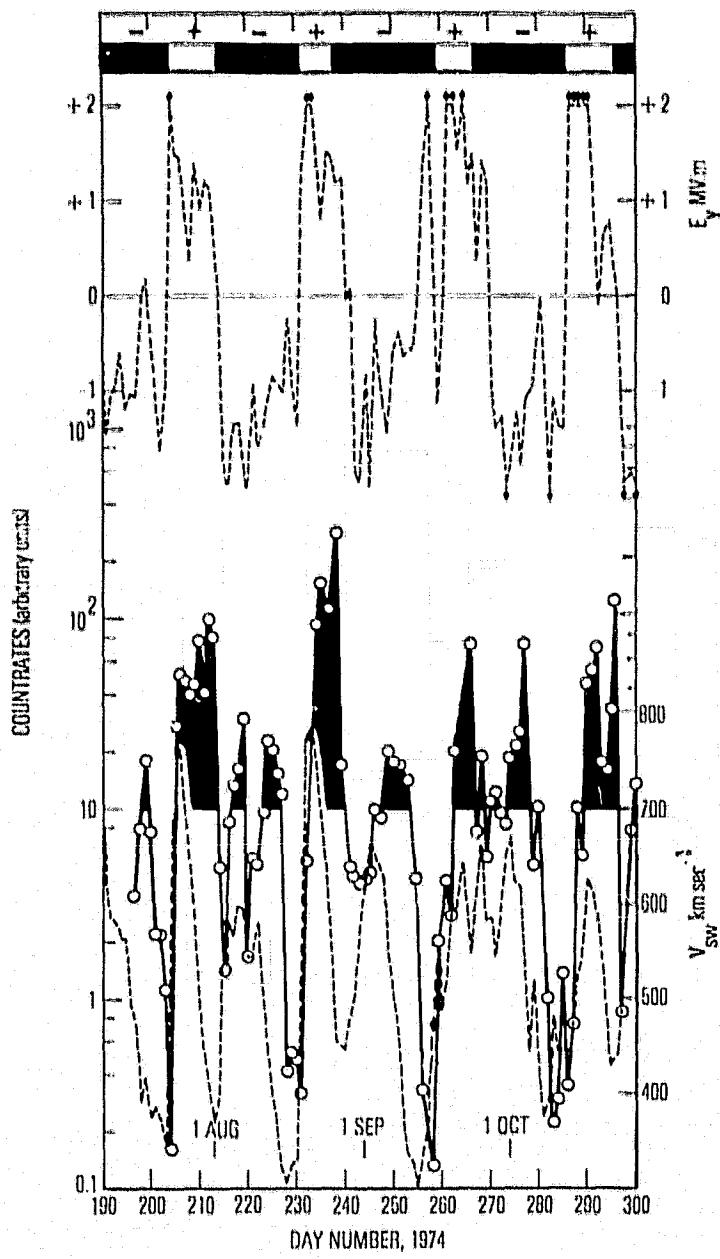


Figure 3. Daily averages of energetic electron count rates observed in the late summer and fall of 1974 by ATS-6 are plotted as a function of Day Number, 1974. Also plotted, at the top of the figure, are the polarities of the interplanetary magnetic field as inferred by Svalgaard (1976), and the strength of the dawn-dusk electric field  $E_y = -(V \times B)_y$ . Local time for all particle data is local noon; the sector boundary transitions are assumed to occur at 0000 UT for the days indicated. Solar wind velocity is shown at the bottom of the figure, (dashed curve, bottom) referred to the right-hand scale. For emphasis we have shaded those portions of the curves where  $E_y > 3.9$  MeV count rates exceed 10/sec. This figure illustrates the mapping of the solar wind velocity structure into the energetic electron flux intensity structure on a time scale of several solar rotations.

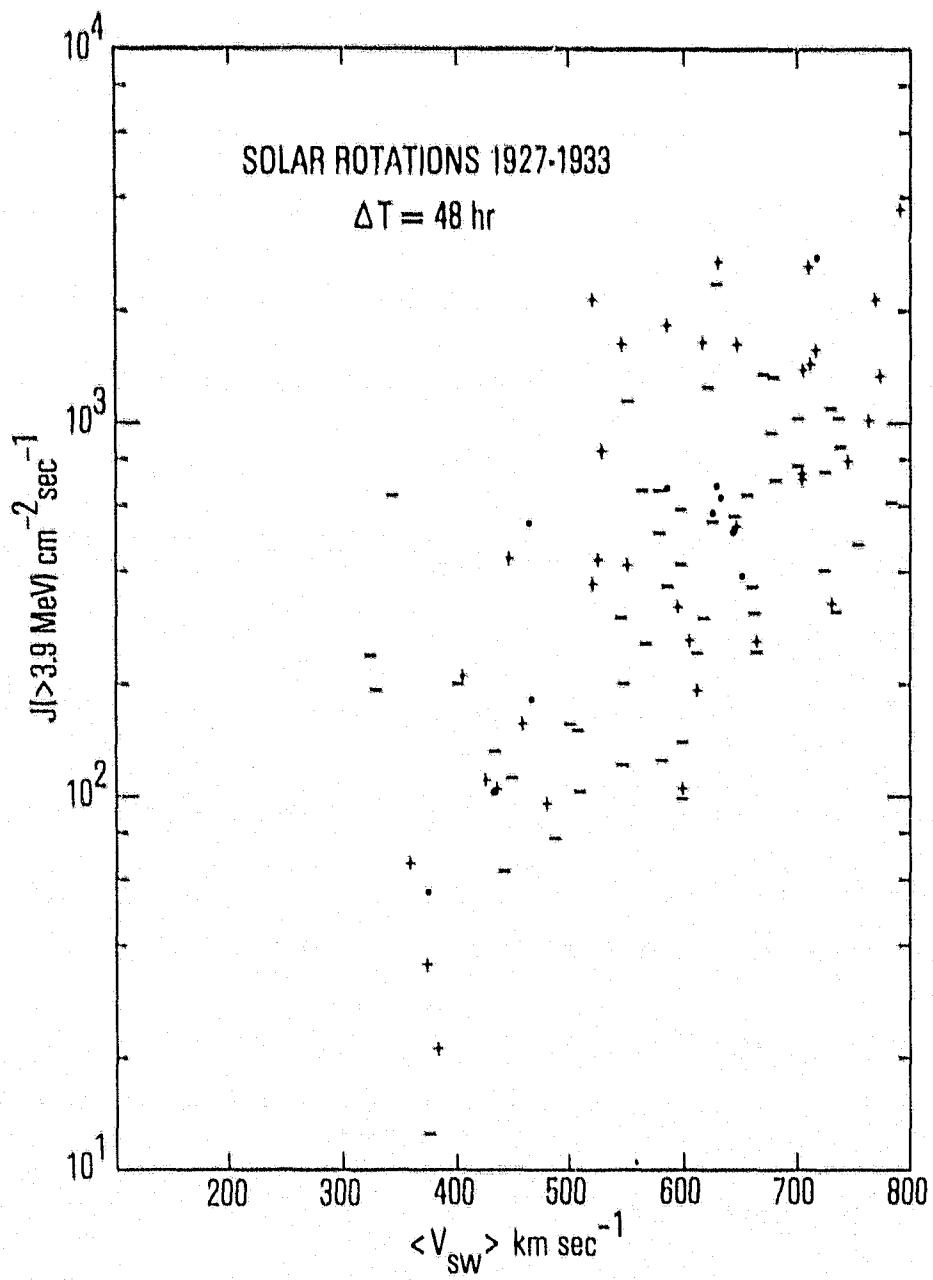


Figure 4. Correlation of daily averages of greater than 3.9 MeV electron fluxes with daily averages of the solar wind velocity. The delay time between solar wind and energetic particle measurements is 48 hours. All data available for solar rotations 1927-1933 (July-December 1974) - a period when high speed solar wind streams were present - are included in this plot. The plus and minus signs indicate the sign of  $E_y = -(V \times B)$ , in geocentric solar-magnetospheric coordinates; data points for which the  $E_y$  sign cannot be determined are simple points.

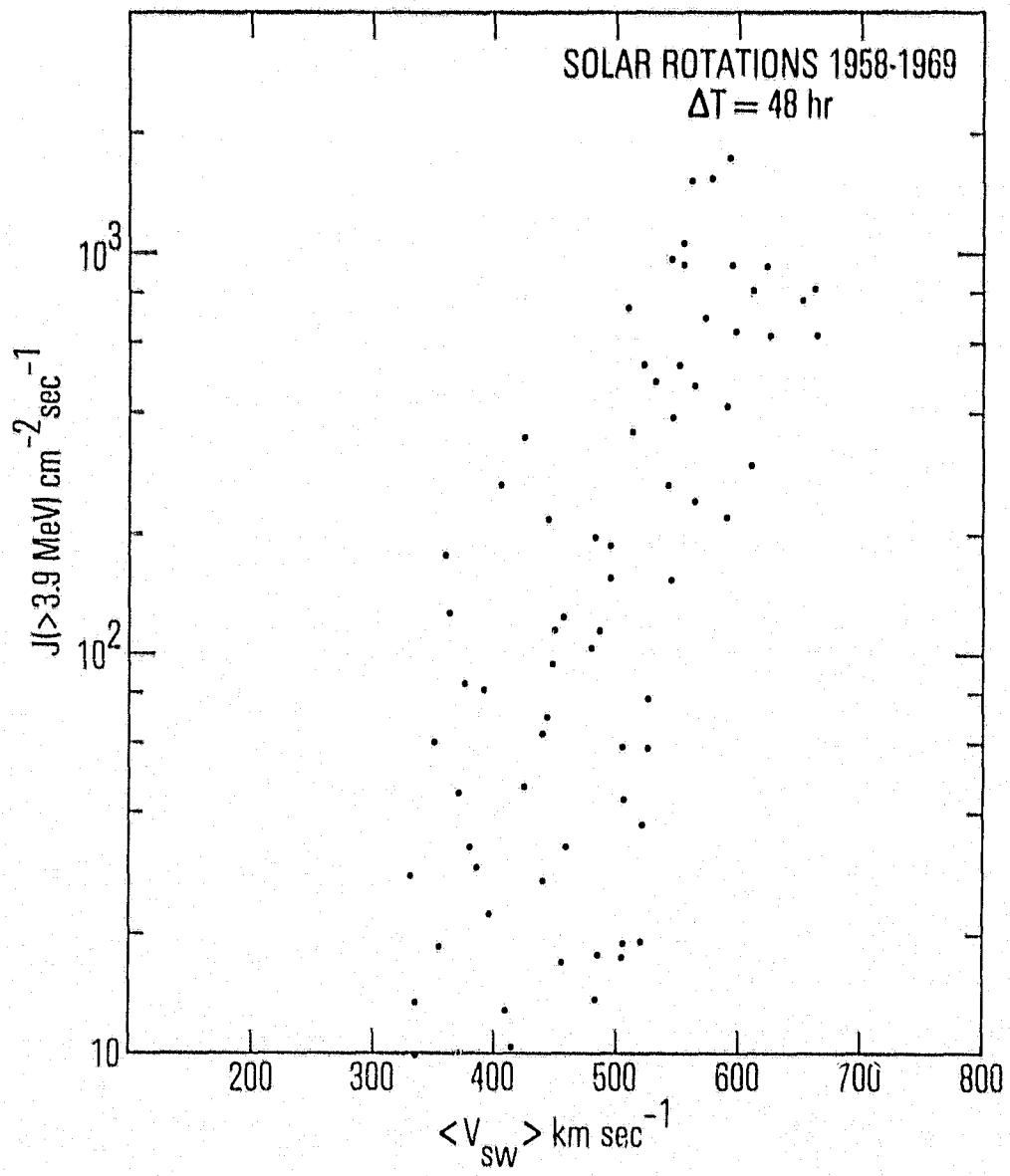


Figure 5. Correlation of daily averages of greater than 3.9 Mev electron fluxes with daily averages of the solar wind velocity. The delay time between solar wind and energetic particle measurement is 48 hours. All data available for solar rotations 1958-1969 (October 1976 - August 1977) - a period of relatively low solar wind velocity - included in this plot.

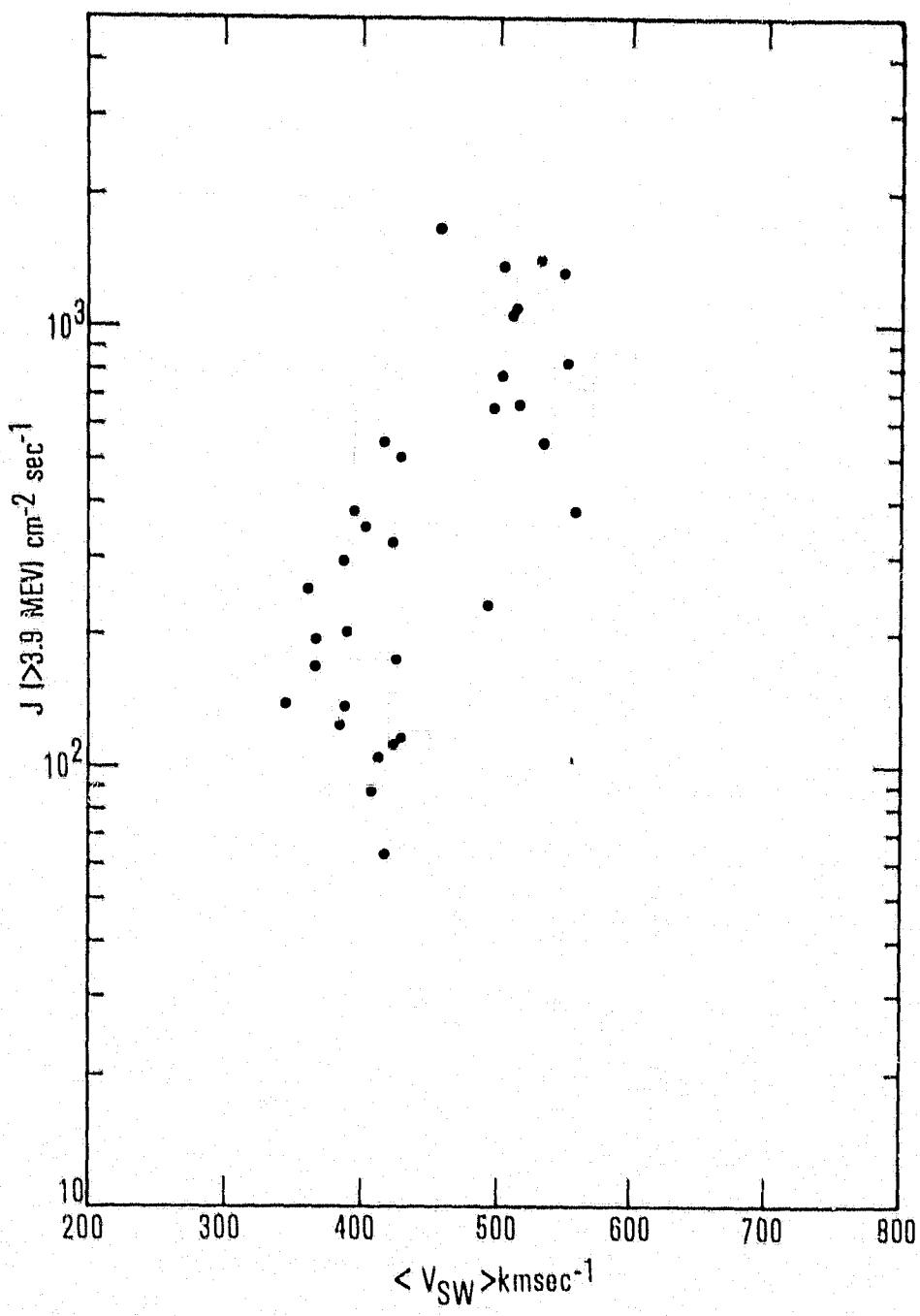


Figure 6. 27-day averages of energetic electrons ( $E > 3.9$  MeV) as a function of corresponding averages of the solar wind velocity. All ATS-6 data from June 1974 through August 1977 are included in this figure, except for a period from mid 1975 through early 1976.

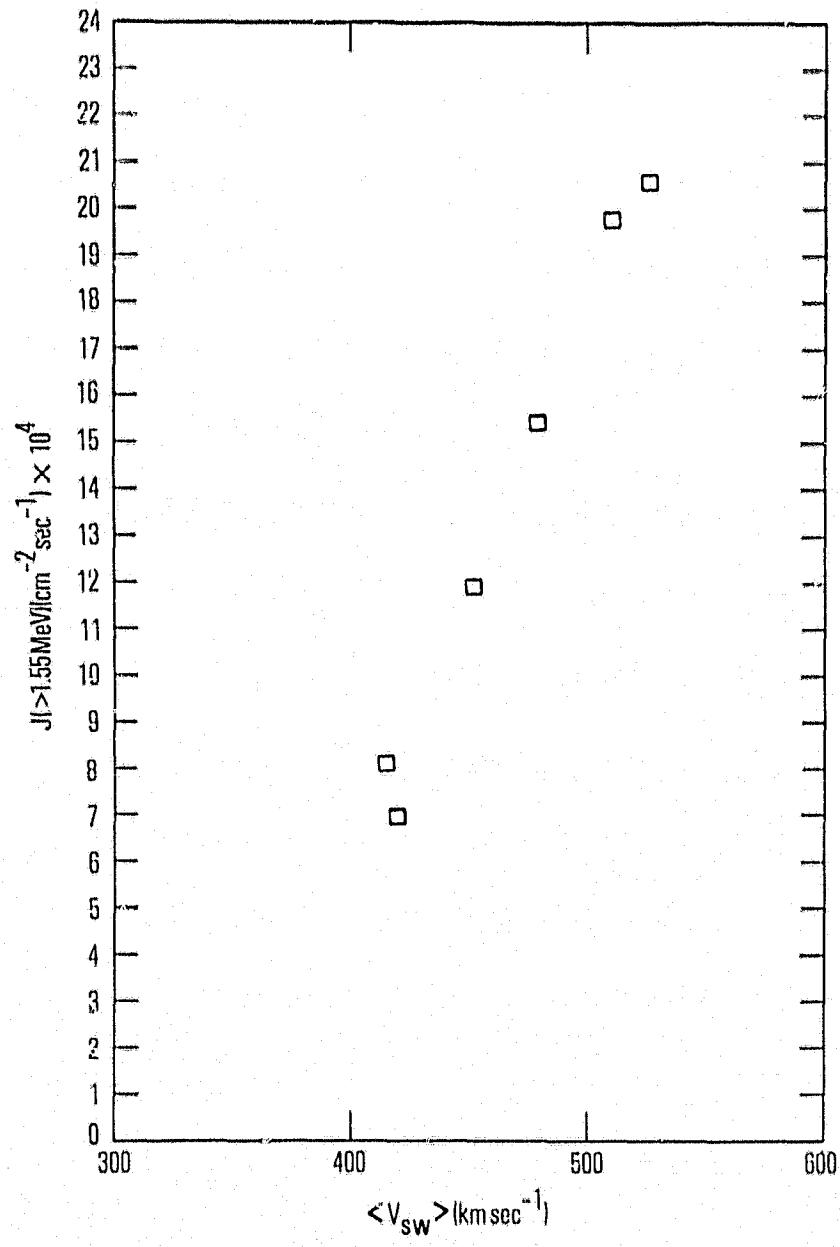


Figure 7. Plot of the semi-annual average of the  $E > 3.9$  MeV electron flux as a function of the semi-annual average of the solar wind velocity. ATS-6 data from mid 1974 through 1977 are included in this plot, excepting the semi-annual average for the last half of 1975 and the first half of 1976.

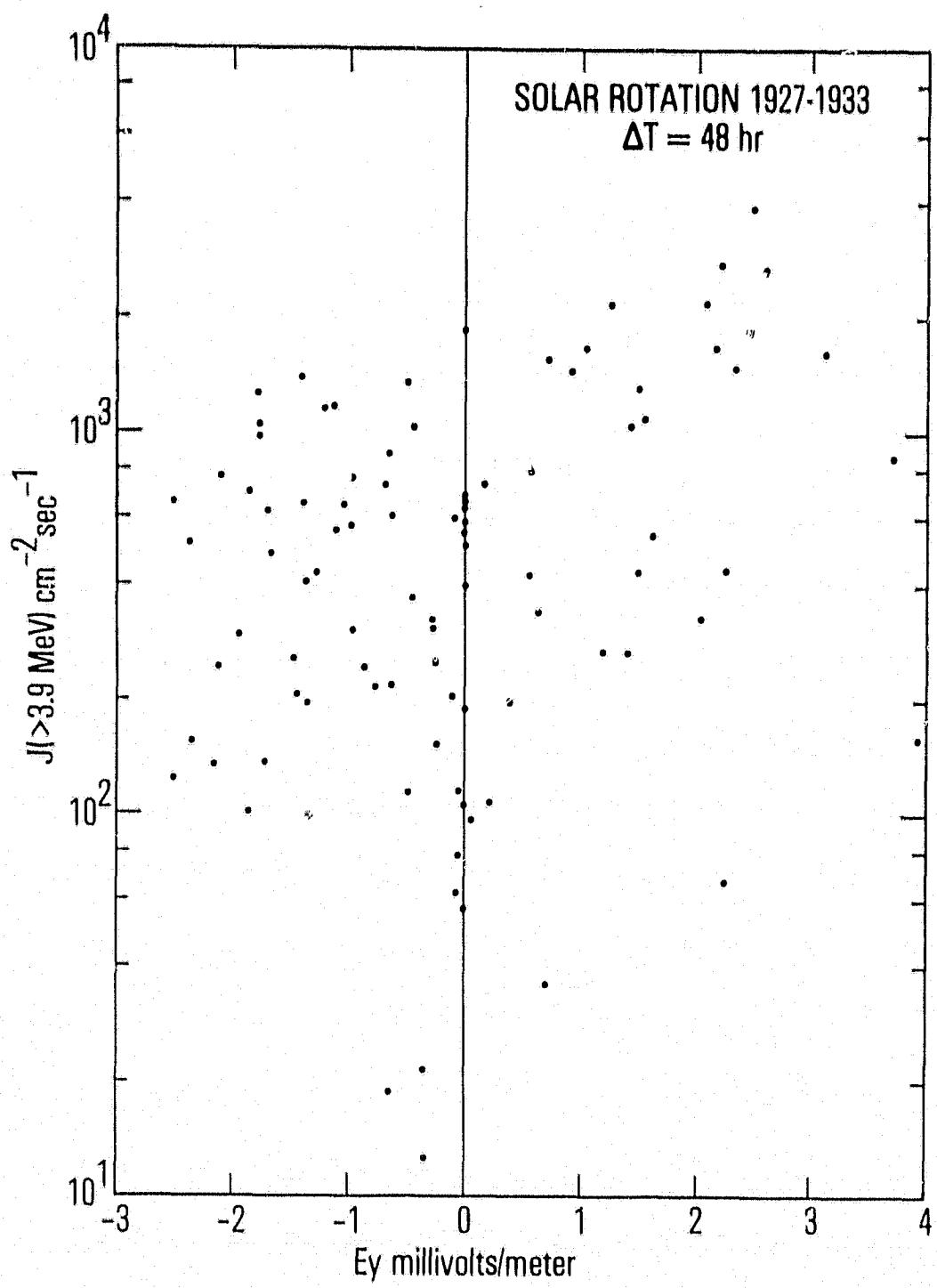


Figure 8. Correlation of daily averages of greater than 3.9 MeV electron fluxes with  $E_y = (V \times B)_y$  in GSM coordinates. Data on this plot are identical to that presented in Figure 4.

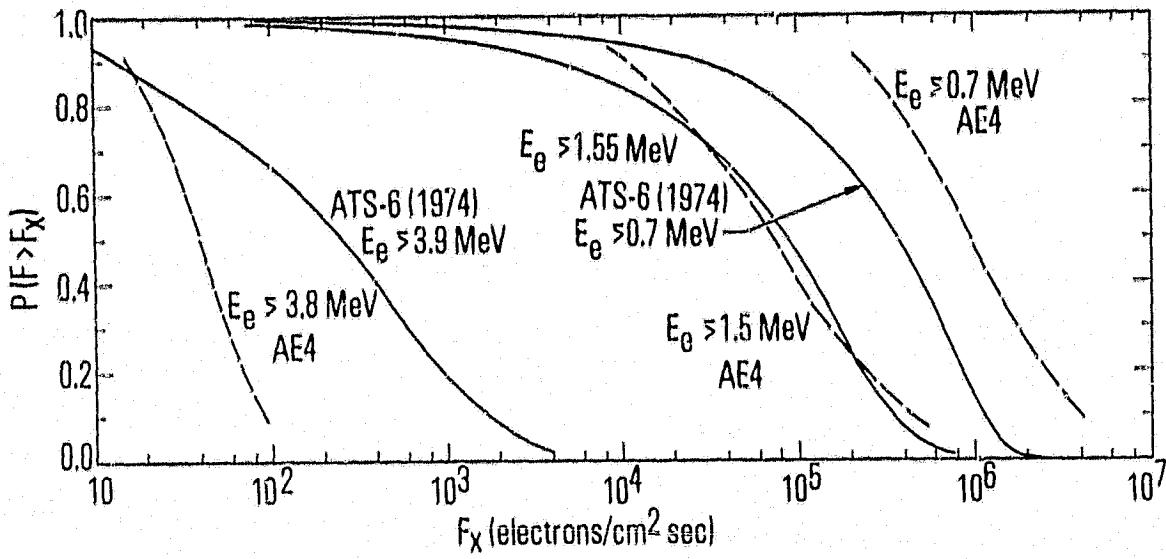


Figure 9. Comparison of  $P(F > F_x)$ , the probability of observing an electron flux  $F$  greater than  $F_x$ , as measured by the Aerospace experiment on ATS-6 during 1974 for several energy thresholds, with the AE-4 model. Significant differences are found at high energies.

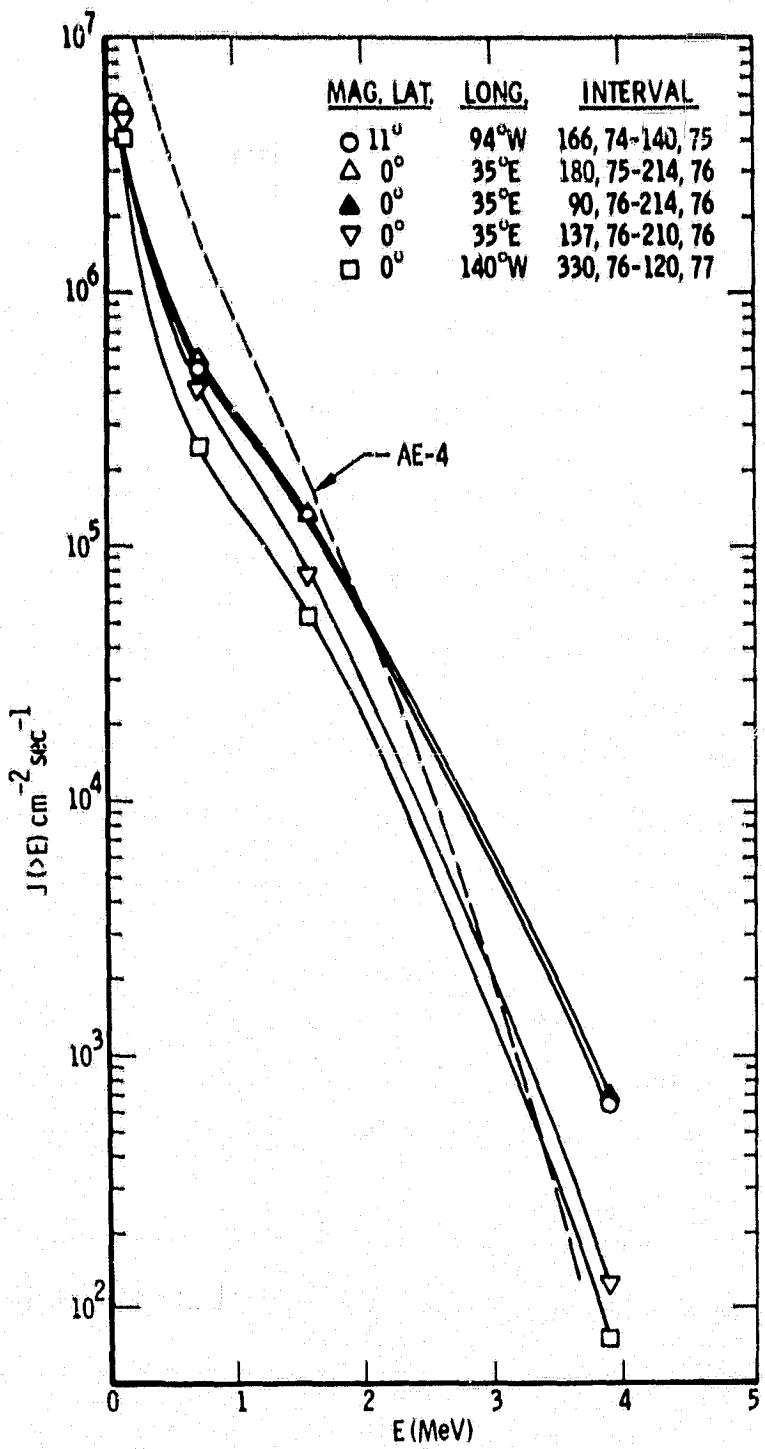


Figure 10. Electron energy spectra obtained by ATS-6 at several longitudes are compared against the prediction of the AE-4 model. Longitudinal effects are, in general, masked by temporal variations.

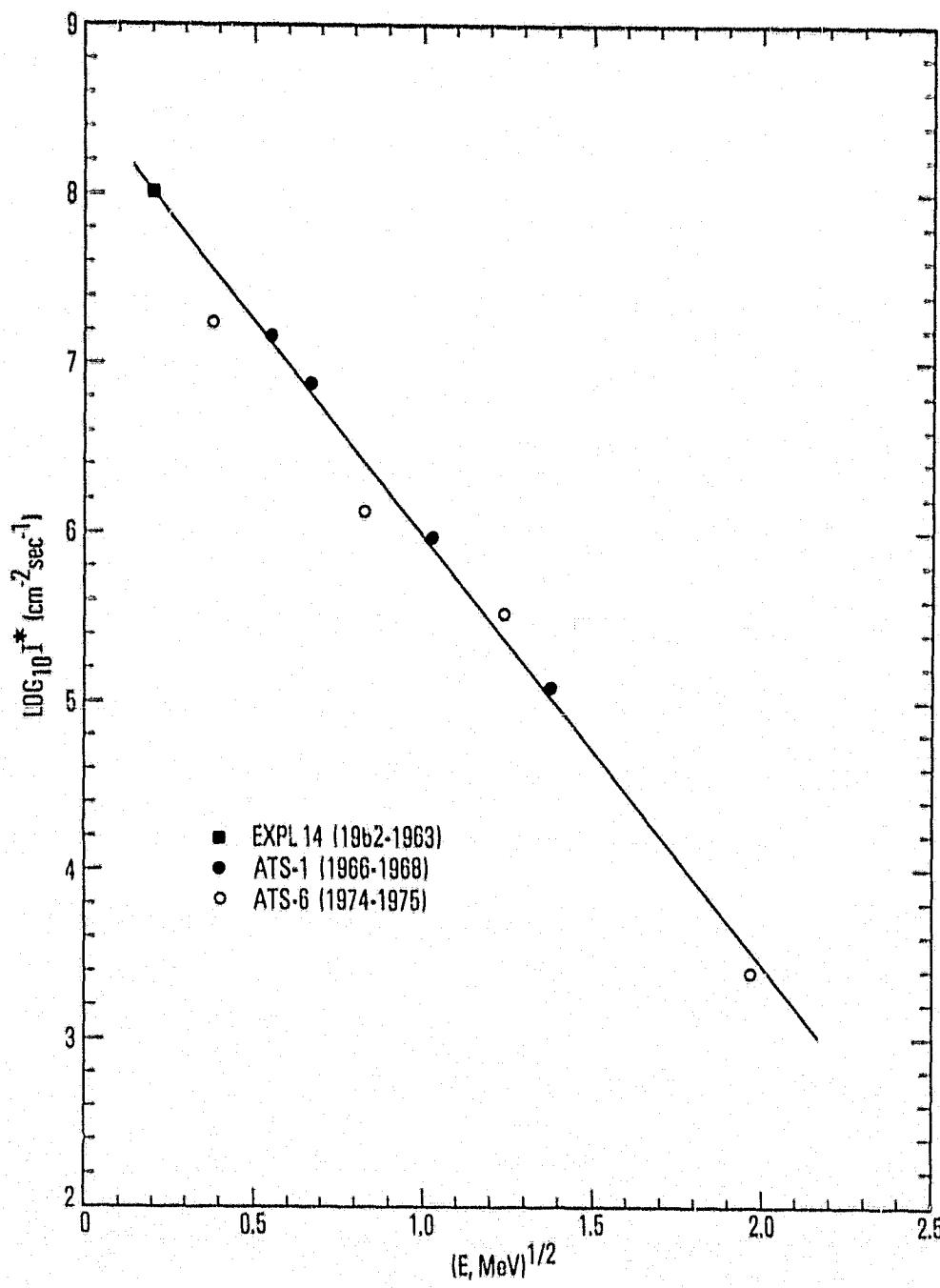


Figure 11. Maximum omnidirectional flux  $I^*$  observed at the synchronous orbit by several spacecraft is plotted as a function of the square root of the energy threshold. This plot summarizes data from ATS-1 (1960-1969), ATS-6 (1974-1975) and also includes the Explorer 14 > 40 keV data point obtained in 1962-1963.

although theoretically unsubstantiated at high energies, fits the Kennel-Petcheck limit derived for > 40 keV electrons. (Ref. C-4.)

4. Short duration (minutes) pulses of energetic protons (> 3.5 Mev) have been observed on occasion. It appears that these proton bursts are associated with relatively rare and unusual substorms which are capable of generating particles whose energy spectra extend into the Mev region. The occurrence of the proton burst is well correlated with the presence of high speed solar wind streams, i.e., high solar wind velocity appears to be a necessary condition for the magnetosphere to generate Mev-type protons via the substorm process. Analysis of data is continuing.

5. Numerous solar proton events were observed during the time our experiment on ATS-6 was operated. No systematic study of these events has as yet been carried out; however these data have been communicated to several scientists who were interested in using our data for correlative purposes.

6. ATS-6 data for 1974 has been submitted to NSSDC. A User's Guide to our data has also been prepared and published. All data for 1975, 1976 and 1978 have also been organized and are ready for submission to NSSDC as soon as NSSDC has verified that our initial input meets the required standards. (Ref. B-6.)

Separately and informally ATS-6 data has been provided to numerous scientists, on request, for use in connection with their research interests.

7. ATS-6 data has been used to aid in the analysis of anomalies and failures which have occurred aboard USAF and commercial spacecraft operating at or near the synchronous orbit. Such analyses have ranged from simple examinations of the ATS-6 data to see if unusual conditions were present in the space radiation environment to the construction of mini-models of the space radiation environment there for the guidance of spacecraft designers and operators.

## C. Technological Findings

### 1. Performance History

The experiment operated as designed since launch with a few anomalies noted below. At the time of writing (June 1979) the experiment continues to function. The operational anomalies we have observed were:

- a. When the experiment reached temperatures below about  $-10^{\circ}\text{C}$ , an open circuit developed in one channel of data. We ascribe this malfunction to a substantial thermal gradient which appears to result in loss of signal in this channel. We suspect that the open circuit develops at or near the detector because it is there that the maximum thermal gradient is expected to occur. This malfunction caused only a minor loss of data. However, it is worth noting that while the experiment was separately tested in thermal vacuum at Aerospace and also tested while integrated with the spacecraft well beyond (below) the temperature at which the anomaly occurred, such testing did apparently not properly simulate thermal gradients.
- b. An intermittent noisy condition was observed in one detector for some local times and some spacecraft operational conditions. It appears that this anomaly is due to the inverse of the condition noted above, i.e., the detector housing protruding through the thermal blanket reached temperatures in excess of those expected and gave noisy data.
- c. Status data from the experiment was lost when the UNH experiment on ATS-6 malfunctioned shortly after launch and interfered

with the EME data system. Loss of these data considerably complicated the analysis of the anomalies described in a) and b) above.

## 2. Summary and Recommendation

Despite the minor anomalies noted above the Aerospace experiment met or exceeded all goals. The long life of the experiment is directly attributable to careful, conservative design of the electronics and detector system. The experiment - and the entire ATS-6 system - survives and continues to operate in a relatively hostile radiation environment. Anomalies a) and b) noted above once again illustrate that it is important to fully and completely test experiments in thermal vacuum under realistic conditions while all systems are operating. Anomaly c) appears to be the result of limits placed on the thermal vacuum testing program at the integrated EME level.

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B. Technical Reports

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B-2. G. A. Paulikas and J. B. Blake, "Final Report on Reduction and Analysis of ATS-6 Data, Contract NASW-2762 (Period of Performance: 1 May 1975-15 July 1975)," ATR-76(7517)-1, The Aerospace Corp. (September 1975).

B-3. G. A. Paulikas and J. B. Blake, "Energetic Electrons at Synchronous Altitude 1967-1977," TR-0078(3960-05)-8, The Aerospace Corp. (17 July 1978).

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B-11. G. A. Paulikas and J. B. Blake, "Final Report, Reduction and Analysis of ATS-6 Data (1 November 1976 to 31 October 1978)," ATR-79(7642)-1, The Aerospace Corp. (13 December 1978).

C. Technical Memoranda

Aerospace Technical Memoranda (ATM's) are limited, internal distribution documents which contain informal descriptions of technical progress. The ATM's listed below provide progress reports and intermediate results less complete than described in the technical reports listed earlier. These documents however do provide insight into the development of ideas and are listed here to complete the historical record of the ATS-6 project.

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